

CHROMITE

ITS PARAGENESIS, MINERAL AND CHEMICAL COMPOSITION

FROM A DISSERTATION SUBMITTED TO THE BOARD
OF UNIVERSITY STUDIES OF THE JOHNS HOP-
KINS UNIVERSITY IN CONFORMITY WITH THE
REQUIREMENTS OF THE DEGREE OF
DOCTOR OF PHILOSOPHY

BY

LLOYD WELLINGTON FISHER

BALTIMORE, 1929



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ORIGIN OF CHROMITE DEPOSITS.

LLOYD W. FISHER.

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INTRODUCTION.

CHROMITE, whether it occurs as an abundant accessory mineral or as a deposit of commercial importance, is restricted to the ultrabasic rocks or their derivatives. The alteration products of the ultrabasics may be serpentine, talc, or carbonate.

The occurrences of chromite are chiefly in the form of pockets or lenses; in schlieren, which are usually much longer than broad; in disseminated deposits; and in chrome sands, which have accumulated in watercourses, owing to the mechanical concentration following the disintegration of a chromiferous rock. The ore bodies vary in size from small, isolated pockets or "pots" as illustrated at Bare Hills, Maryland, and Hestmandø, Norway, to larger masses containing many thousand tons, as at the famous Wood Mine, Lancaster County, Pennsylvania, the Castle Crag Mine, Dunsmuir, California, and the Great Dyke and Selukwe deposits of Southern Rhodesia.

Opinions in regard to the relations between the periods of crystallization of chromite and the groundmass minerals are

divergent. Some investigators have regarded chromite as the earliest constituent to crystallize but other have shown evidence that chromite may form at later periods. The study of chromiferous rocks from the important chromite regions of the world has yielded abundant evidence that much chromite is formed during the late magmatic period. The writer has recognized three distinct periods of crystallization of chromite: (1) Chromite of the early magmatic period is the first mineral to crystallize. An overlap in the periods of crystallization of chromite and olivine is often noted; (2) Chromite of the late magmatic period is later than the groundmass minerals and occurs in zones of crushed olivine, in cleavages of the cleavable minerals and as replacements of the earlier pyrogenic silicates of the groundmass; (3) Chromite of the hydrothermal period is definitely later than the pyrogenic silicates and is associated with deuteric minerals; the chromite of this period was formed by either early or late hydrothermal solutions.

The writer takes this opportunity to express his gratitude to all those who have contributed materials for this study and to Professor Joseph T. Singewald, Jr., who outlined and supervised the problem.

DESCRIPTION OF CHROMITE ORES.

Chromite in Thin Section.

Form.—Chromite, in thin section, shows varying degrees of perfection of crystal form. In unaltered rocks chromite of early magmatic origin is usually characterized by lack of fracturing. Forms may be euhedral and subhedral. The subhedral forms probably originate through corrosive action by the solutions that carried the constituents that formed the groundmass minerals. Chromite of the magmatic period is invariably in small grains, occurring either singly or in aggregates. Vogt has applied the term "synneusis structure" (together-swimming) to such accumulations (Fig. 1). Bowen¹ does not accept Vogt's view that such accumulations are caused by an attraction of one crystal for

¹ Bowen, N. L., "The Evolution of Igneous Rocks." Princeton University Press, 1928.

another, but suggests that they are due to a sort of pseudomorphism after a resorbed mineral.

Euhedral grains of chromite, embedded in a groundmass of enstatite or bastite, may show a structure similar to that of the chondrules of meteorites. Anhedral forms are more predominant than euhedral and subhedral types. They may or may not be fractured. Diller² believed that anhedral forms crystallized under conditions of interference. Solution of original euhedral grains by late magmatic or early hydrothermal solutions is believed, by the writer, to be equally responsible for the development of such forms. Small apophyses of chromite thus developed from the original grain may penetrate groundmass minerals.

Fracturing.—Fracturing of chromite grains is more pronounced in the hydrothermally altered ultrabasic rocks than in the fresh varieties. Incipient fractures serve as solution channels and the force of crystallization of later materials within these channels may split off peripheral portions of the grain or pass completely through the chromite. Fracturing may be more or less regular and produce a "mitred-structure." This term is applied to those grains which have been fractured in such a way that the removal of the material deposited in the fracture would allow dovetailing of the adjacent parts of the chromite.

Color.—Chromite commonly shows translucency in tones of yellowish brown through orange brown to deep cherry red. Some grains are black and show no translucency even on thin edges. A peculiar color phenomenon has been noted by the writer and others. The central portion of a chromite grain may be yellow-brown by transmitted light, although a continuous or discontinuous black border may surround the translucent center. Black opaque lines may traverse the entire grain without respect to cleavage, fracture or outline of the chromite. Dresser³ noted this peculiarity in Canadian chromite specimens and found that

² Diller, J. S., "Recent Studies of Domestic Chromite Deposits," Am. Inst. Min. Eng. Bull. 153, 1919, pp. 2018 et seq.

³ Dresser, J. A., "Preliminary Report on the Serpentine and the Associated Rocks of Southern Quebec," Can. Geol. Surv. Mem. 22, 1913.

the opaque portion was richer in ferric iron and poorer in chromic oxide than the translucent center. Phillips⁴ observed the same features in chromite of the Shetland Islands, and favored the view that the black material was grown upon earlier-formed chromite. Lewis observed the same features in the North Carolina occurrences. The association of penninite with chromite grains showing this color phenomenon led him to the conclusion that alumina and magnesia were subtracted from the peripheral portion of the chromite to form the penninite sheath. This subtraction caused a relative increase in the ferric iron content of the peripheral zone of the chromite and opacity resulted. An examination of Lewis' slides by the present writer shows that there is no relationship between the zoning of colors in the chromite and the associated groundmass minerals. Solution of chromite is indicated in many cases. The writer favors the view that these black lines represent deposition of ferric oxide, possibly as a cement, along narrow or incipient fractures in the chromite.

The common colors noted in chromite grains are yellowish brown, yellowish red, reddish brown, coffee brown, cherry red and black. Analyses of ore specimens compared with thin sections from the analysed material indicates that the lower the content of chromic oxide the more yellow the color of the chromite becomes. High chromic oxide content is commonly indicated by shades of deep cherry red. There is no apparent correlation between the black chromite grains and their chemical analyses. Separation of chromite, from the associated groundmass minerals, by means of heavy liquids, indicates that the mineral association of the chromite is in no way connected with the chemical composition of the ore mineral.

Minerals Associated with Chromite.

The most important common associate of chromite is serpentine. Johannsen⁵ lists 16 varietal serpentines and separates

⁴ Phillips, F. C., "The Serpentine and Associated Rocks and Minerals of the Shetland Islands," *Quart. Jour. Geol. Soc.*, 83, 1927, pp. 622-652.

⁵ Johannsen, Albert, "The Serpentine of Harford County, Maryland," *Md. Geol. Surv.* 12, 1928, p. 242.

them on the basis of their occurrence as massive, lamellar, or fibrous forms. Minor differences in structure and texture have led to this multiplicity of names, which is entirely uncalled for. The writer limits his use of descriptive names to the four most common types of serpentine that are recognizable macro- and microscopically. These are:

Antigorite.—This is commonly developed from olivine, the alteration beginning along fractures and preserving the characteristic mesh structure superimposed by the network of fractures. The stated pleochroism of antigorite is accidental rather than essential and has seldom been noted by the writer.

Bastite.—This mineral commonly forms pseudomorphs after enstatite and is easily distinguishable from the other serpentines on the basis of parallelism of its fibers. Interlocking fibrous zones are developed in completely serpentinized enstatites. If diallagic parting has been superimposed on original enstatite grains it will be reflected in the inclined extinction of the zones of bastite.

Williamsite.—This apple green to jade green, translucent variety of serpentine is characteristic of the Line Pit (State-Line Serpentine Belt). It appears fibrous and closely resembles antigorite but has higher interference colors. The arrangement of the fibers or plates suggests enstatite as the original mineral.

Chrysotile.—This is the fibrous form of serpentine, with fibration normal to the enclosing walls of the thin veinlets in which it usually occurs. It also resembles antigorite but is characterized by delicate fibers that show positive elongation.

Chlorites.—One is rarely able to distinguish between kämmererite, a chlorite, and kotschubeite, a clinocllore, in the hand specimen. Penninite is determined with equal difficulty. Kämmernerite may be developed in large, well-defined, micaceous forms. It is colorless in thin section and lacks the pleochroism ascribed to it by Weinschenck and others. Penninite is denominated by anomalous lavender blue interference colors and kämmererite shows abnormal colors, commonly deep blue to rust brown. Kotschubeite has much lower birefringence than kämmererite, shows marked pleochroism and is always negative in character.

Stichite.—This mineral is reported from Dundas, Tasmania. Specimens of the material were sent the writer by Blake; these show a light strawberry pink to a pale lilac colored incrustation on compact, fine-grained serpentine. Stichite is a complex hydrous magnesium carbonate with chromic oxide, and resembles brugnatellite chemically. Optically it is closely related to kämmererite although it is easily distinguishable from the chlorite on the basis of the radial arrangement of fibers, which are invariably grouped about a center or nucleus that is commonly an anhedral chromite. Chrysotile often shows the same mode of occurrence as stichite and it is suggested that stichite is formed as a pseudomorph after chrysotile.

PARAGENETIC RELATIONS OF CHROMITE.

The present study of specimens from many localities brings out the fact that much of the chromite is of primary crystallization and that it is of both early and late magmatic origin. There is evidence of solution and redeposition of this chromite by hydrothermal processes. It is difficult to draw a sharp line between deposits that are strictly magmatic segregations and those that have been formed largely by hydrothermal solutions.

A comparative study of the chromiferous rocks was made in order to ascertain whether there is any decided difference in the mode of occurrence of chromite in rocks which show varying degrees of metamorphism.

In Fresh Rocks.

Chromite of the fresh rocks is usually characterized by lack of fracturing. Euhedral and subhedral forms may be present. The essential minerals of the fresh rocks are olivine and enstatite in varying proportions.

Alaska.—Chromite occurs as unfractured, subhedral grains in zones of crushed olivine in the comparatively fresh dunite of Claim Point. The olivine grains of the groundmass are elongated and granulated. Wavy extinction of olivines is noted. The chromite is unfractured and represents a product of late magmatic

origin that was formed after the processes that caused granulation and elongation of the olivines had died out. That chromite was formed after the olivine is indicated by several features: (1) unfractured chromite occurs in highly fractured olivines; (2) outlines of chromite grains transect olivine boundaries; (3) apophyses of chromite are developed in the cleavages of monoclinic pyroxenes (Red Mountain Area); and (4) chromite in finely granulated olivine is unfractured.

New Zealand.—The chromite deposits of New Zealand occur as impregnations and streaks in the ultrabasic rocks of the upper basin of Takaka river, 30 miles northwest of Nelson. The original dunite of von Hochstetter is from this general locality.

The New Zealand rocks, studied by the writer, are practically unaltered dunites in which chromite occurs as ill-defined streaks that show mitred-structures. The boundaries between the chromite grains and adjacent olivines suggest contemporaneity of crystallization of these two minerals. Kelyphitic rims of chrysotile are developed around the chromite grains and show no staining by chromiferous solutions. There are quite a few veinlets of chrysotile traversing the groundmass minerals, and chromite in elongated grains between the fibers of such veinlets is the only evidence of chromite of late crystallization.

Although the chromiferous rocks of New Zealand and of North Carolina bear striking resemblances, it is to be noted that in the former locality serpentinization and chloritization are not prominent features.

Other Localities.—Chromite occurs interstitially between olivine grains in the fresh dunite of Balsam Gap, North Carolina, and between olivine and enstatite grains in the unaltered peridotite of Selma, Oregon. Euhedral grains of chromite transect large olivine crystals embedded in a trachytoidal groundmass of bytownite-anorthite in the peridotites of the Isle of Skye.

The chromite of the fresh rocks described above is undoubtedly of late magmatic origin.

In Hydrothermally Altered Rocks.

The chromiferous ultrabasic rocks are composed almost entirely of mafic minerals. The occurrence of this type of mineral is conducive to rapid, and, in places, complete alteration. Olivine is, perhaps, the predominant mineral of the ultrabasics. It is unstable under ordinary conditions of weathering so that its presence in large amounts is a causative factor of alteration. The most common processes of alteration noted in the study are: (1) serpentinization, (2) chloritization, (3) talcization and (4) hornblendization.

The chromite of hydrothermally altered rocks may or may not be fractured but the outlines of the grains are more predominantly anhedral. Chromite that was deposited by the hydrothermal solutions that produce such minerals as talc, tremolite, actinolite, anthophyllite, serpentine, chlorite and magnesite is termed hydrothermal chromite. Much of this type of chromite might have resulted from the solution and redeposition of chromite of the magmatic stage.

Hydrothermal amphiboles, chlorites and talc are well developed in the chromiferous rocks of Norway and North Carolina. The suite of minerals in each of these areas is practically the same. Penninite, anthophyllite, actinolite, talc, calcite and serpentine are the typical minerals associated with the deposits of these two areas, although serpentine is developed in very minor amounts.

Norway.—The original saxonitic rocks of Hestmandø, Norway, have been altered to an advanced stage by hydrothermal solutions. Calcite, talc, actinolite and penninite have been formed. Calcite replaces olivine in many of the examples studied. Olivine relicts are included within the enstatites and suggest that the former mineral has been replaced by the latter. In practically all the thin sections of the Norwegian chromiferous rocks, which were sent the writer by Professor J. H. L. Vogt, there is evidence of solution of chromite and its redeposition either contemporaneous with, or subsequent to, the formation of the deuteritic minerals.

In the Selsovik area the same suite of minerals has been developed. Elongated grains of chromite of late magmatic origin

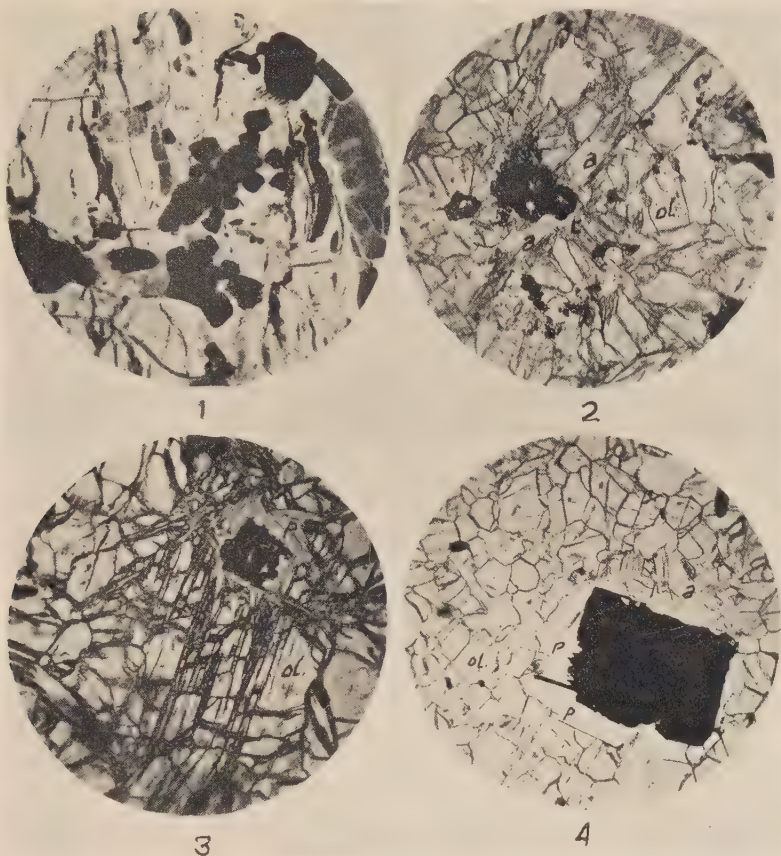


FIG. 1. Euhedral and subhedral grains of chromite in accumulative structures—"synneusis"—occurring in a bastitic groundmass. Dark gray (right) limonitic stain on bastite. Rhodesia. $\times 12$.

FIG. 2. Chromite grain penetrating actinolite (*a*) blade. A thin sheath of talc (*t*) surrounds chromite. Olivine groundmass (*ol*). Norway. $\times 12$.

FIG. 3. Subhedral grain of chromite completely sheathed by penninite (*p*) in an olivine (*ol*) groundmass. The groundmass is practically fresh. Webster, North Carolina. $\times 12$.

FIG. 4. Subhedral grain of chromite with an apophyse injected into penninite (*p*) plates. Actinolite (*a*) and olivine (*ol*). Burnsville, North Carolina. $\times 12$.

occur between olivine grains, in the fractures of olivine and in the cleavages of enstatite, and across the cleavages of the deuteritic minerals. In Fig. 2 an anhedral chromite grain penetrates an actinolite blade which is optically continuous on each side of the chromite. A thin sheath of talc separates the chromite from the actinolite.

Chromite of the late magmatic stage is more abundant in the Norwegian occurrences than that of the early magmatic. Hydrothermal chromite, developed in cleavages of penninite, enstatite and actinolite is also of greater importance than early magmatic chromite.

North Carolina.—The greatest amount of alteration of the North Carolina chromite deposits has been caused by chloritization. The chromite masses are invariably associated with penninite and with talc. The manner of association of the hydrothermal minerals with the chromite suggests a genetic relationship between these minerals. Some black chromite grains are completely enclosed in penninite (Fig. 3). Thin, elongated apophyses of chromite project from the original grain into the cleavages of the penninite as is illustrated in Fig. 4.

Another thin section shows a penninitic zone in contact with fresh olivine. The character of the boundary indicates that the chlorite has replaced the olivine. Chromite grains are nearly lacking in the olivine portion of the groundmass and in the penninitic zone near the contact. Beyond the contact, however, chromite is abundant in the penninite. Subhedral, unfractured forms predominate and cut across the cleavages of the chlorite plates or penetrate between them. The penninite zone represents solution along a fracture. The chromite deposited was carried in solution by the hydrothermal waters that replaced olivine with penninite.

The chlorite in the North Carolina rocks varies between kämmererite and penninite. Specimens from Webster show kämmereritic zones similar to the penninite zones described above. A thin veinlet of magnesite is developed in such a kämmererite zone. The only chromite in the zone is a discontinuous streak

of euhedral grains parallel to the magnesite veinlet. It was deposited by the solutions that deposited the magnesite.

The almost invariable development of either talc sheaths or penninitic zones around the chromite of North Carolina is indicative of a genetic relationship between the chromite and the deuteric minerals. A small portion of the North Carolina chromite is regarded by the writer as representing chromite of the early magmatic stage. Most of the chromite of the North Carolina deposits is of hydrothermal origin.

Pennsylvania.—The original chromiferous rocks of the State-Line serpentine belt of Pennsylvania and Maryland were saxonites, dunites, wehrlites and websterites. Thus they resemble the Norwegian and North Carolina rocks chemically. Serpentinization, however, has been the dominant process of alteration in the State-Line belt. The hydrothermal minerals described in the preceding areas are almost entirely lacking in the serpentines of Pennsylvania.

The best example of chromite associated with penninite is from the famous Wood Mine, Lancaster County, Pennsylvania. According to Glenn,⁶ "the Wood mine stands alone among chrome mines. It is truly an ore shoot, a vein, as are the copper mines in the crystalline rocks at Capelton, in the province of Quebec, or at Ely, or at Elizabeth in Vermont." Glenn also stresses the smooth and well-defined footwall.

Deweylite and magnesite fill small fractures which extend radially for half an inch into the serpentine surrounding the chromite. These minerals originated during the period of hydrothermal activity. The rocks on the dump carry clinocllore, kämmererite, uvarovite, zaratite, deweylite, brucite, magnesite and hydromagnesite.

Chromite of the Wood mine is characteristically black in color, although translucent reddish brown and yellowish grains are not uncommon. The ore mineral occurs as disseminated particles in serpentine. Bastite and antigorite are abundantly developed and

⁶ Glenn, William, "Chrome in the Southern Appalachian Region," *Am. Inst. Min. Eng. Trans.*, 23, 1895, p. 481.

indicate that the parent rock was a saxonite. Penninite is seen in some of the slides, and wherever this mineral is developed in abundance chromite veinlets or stringers of considerable size are associated with it. Fig. 5 shows such a veinlet of chromite in penninite. The chromite veinlet is separated sharply from the olivine by a selvage of penninite. No penninite is developed in the olivine groundmass, and chromite occurs but sparingly in the olivine.

In other slides from the same mine much chromite is associated with the hydrothermal bastite and magnesite as shown in Fig. 6.

Much of the chromite of the Wood Mine is late magmatic, although considerable hydrothermal chromite was brought in by the same solutions that penninitized and serpentinized the original rocks.

California.—Outcrops of magnesian rocks are abundant along the Pacific Coast. California has been the most important chrome ore producer in the western United States. The belt of chromiferous rocks, which is best developed in San Luis Obispo, Alameda, Placer, Glenn, Tehama, Siskiyou and Del Norte counties, California, passes into the Blue Mountains of Josephine and Curry counties, Oregon.

The California studies by the writer were based largely on the thin sections of specimens from the Castle Crag Mine, Dunsmuir, Shasta County, which were used by Diller in his descriptions of the California deposits. The ore occurs as disseminations in pyroxenite, dunite and saxonite, Serpentinization has been the chief type of alteration of these ultrabasics. Diller⁷ arrived at the conclusion that in most cases the crystallization of the chromite antedated that of the silicates and that the mutually interlocking anhedral boundaries of the chromite and the silicates, indicates, at most, contemporaneity of the periods of crystallization.

The writer's conclusions regarding the Dunsmuir deposits are not fully in accord with those of Diller and are as follows:

⁷ Diller, J. S., "Chromite in the Klamath Mountains, California and Oregon," U. S. Geol. Surv. Bull. 725, 1921.

P

1. The presence of elongated masses of chromite with irregular boundaries against enstatite indicates that the former mineral penetrated fractures and replaced, in part, the enstatite.

2. Where associated with olivine rocks, the chromite invariably shows anhedral to subhedral forms, and not subhedral to euhedral forms, as suggested by Diller. Tongues of chromite have replaced original olivines.

3. The relations of chromite to olivine are distinctly those of replacement, and the bordering rims of serpentine indicate that the chromite was deposited by the same hydrothermal solutions that caused serpentinization.

4. Where chromite occurs in partially serpentinized rocks it is not in the olivine but is sheathed by a zone of serpentine. This feature recalls the penninite sheaths of the North Carolina deposits. It is not likely that serpentinization could affect only the contacts between chromite and olivine. The relations suggest that the chromite was deposited when the serpentinization occurred.

5. Where the chromite is associated with penninite, there is a definite relationship between the elongation of the penninite shreds and its outlines. This suggests that the chromite postdates the penninite. The alternate view, however, that the chromite might have replaced the enstatite prior to the development of the penninite, is not overlooked.

Nodular chromite is typical of the deposits of New Castle, Eldorado county. Some of the specimens show a nodular chromite surrounded by a thin sheath of tremolite, and in others, definite banding of chromite has occurred in a completely carbonated rock. Where tremolite is developed it is invariably restricted to areas of chromite and suggests a genetic relation between the tremolite and the chromite.

The chromite deposits of California show all gradations from chromite of late magmatic origin to hydrothermal origin, the latter type being definitely associated with the serpentinization of the ultrabasics.

Oregon.—Westgate⁸ outlines in brief the geology of the Baker and Grant counties chromite deposits. In discussing the origin of the chromite, Westgate eliminates the idea of origin due to circulating waters after solidification. He believes that the chromite and the silicates belong to the same general period of formation and that subsequent movements in the serpentine, due to volume increases, are responsible for the shape of the ore bodies. Finally, Westgate is unable to decide whether the chromite is due to early crystallization of the more basic minerals or whether it was introduced toward the end of the period of solidification after the main mass of the body was substantially solid.

The writer's study of specimens from Sexton Peak, Josephine County, and from Mormon Basin, Baker County, leads him to the conclusion that much of the chromite occurs as a replacement of the groundmass minerals and is, therefore, of late magmatic origin.

Washington.—A study of the chromiferous rocks of the Cypress Island and Mt. Hawkins areas shows that the origin of these deposits is different from that of the California and Oregon deposits. The original rocks of both areas were strongly dunitic in character, although the development of much bastite in the Cypress Island specimens indicates a rock more closely related to saxonite. The color and the general character of the chromite from these two widely separated localities do not vary greatly. The lack of euhedral form, and the occurrence of peripheral inclusions of olivine in the chromite together with the tonguing-out of chromite between olivine grains suggests a progressive overlap in the periods of crystallization of olivine and chromite. The major portion of the chromite is believed to have been well crystallized when olivine commenced to freeze, although there is evidence that the amount of chromite contemporaneous with, and later than, the olivine is not entirely insignificant.

Transvaal.—The chromite deposits of the Transvaal, located in the Bushveld Complex, are peculiar in that they are associated

⁸ Westgate, L. G., "Deposits of Chromite in Eastern Oregon," U. S. Geol. Surv. Bull. 725, 1921, pp. 37-60.

with enstatite or hypersthene rocks (now serpentized) and anorthosites. There are two separate chromite occurrences in the Transvaal, the Rustenburg and Lydenburg districts.

Rustenburg District: This district lies in western Transvaal. Chromite has been found at 12 localities in a more or less well-defined zone that has been traced for 28 miles. In some places the width of the ore outcrop is 30 feet.

Lydenburg District: This district lies in the eastern part of the Transvaal and the norite belt here reaches a maximum width of one and one half miles, outcropping almost continuously around the entire complex.

The principal chromite deposits are situated on the Grootboom farm and consist of two workings located on opposite sides of a spur. The lower portion of the Complex is the ore-bringer and it consists of bronzite and feldspathic bronzitite.⁹ The character of the rocks and their sequence are indicative of a synclinal structure similar to that of the Great Dyke of Southern Rhodesia. A section, given by Wagner, follows:

600 FEET NW. OF NO. 14 ADIT, MINE NO. 1.

Anorthosite with big crystals of diallage	
Coarse pegmatitic bronzitite.....	½ foot
Chromitite.....	½ inch
Anorthosite.....	4 to 8 in.
Chromitite.....	1 foot
Bronzitite.....	½ to 1 in.
Chromitite.....	7 inch
Bronzitite.....	½ foot
Chromitite.....	4 feet
Bronzitite.....	½ foot
Chromitite.....	1 foot
Footwall feldspathic bronzitite	
Aggregate thickness of chromitite seams.....	6 ft. 7½ in.

The chromite in thin section shows well developed crystal form. The color of the grains varies from a yellowish to reddish brown and no black grains have been noted in the specimens studied. Rounded phenocrysts of yellowish to brownish bronzite and diallage are literally "peppered" with small, euhedral chromites.

⁹ Wagner, P. A., personal communication.

Chondrule-like structures are noted and in these a thick outer zone of chromite encloses fairly fresh enstatite or diallage. In other cases the chromite appears to completely envelope the pyroxene crystals. The gradual transition from pure ore to barren rock, and the petrographic study of thin sections indicate that the chromite is a product of the magmatic period and that the concentration in seams is probably due to gravitational differentiation.

Southern Rhodesia.—The Great Dyke of Southern Rhodesia is a basic intrusive younger than the rocks of the Bushveld Complex. The dike is approximately 300 miles in length and four miles in width. Synclinal structure apparently prevails in the dike in the vicinity of Makwiro. The marginal facies of the mass consist mainly of an altered and rotten harzburgite (saxonite). Above this basal harzburgite is a thin chromite-bearing serpentine which does not extend much further south than Makwiro. The serpentine is capped by a thick layer of pyroxenite which is, in turn, overlain by an equally thick feldspar-rich norite.

The rocks of the dike are composed in general of four essential minerals, enstatite, labradorite, olivine and augite, with accessory chromite and platinum. The variation in proportions of these four essential minerals has resulted in the formation of at least 15 distinct types of ultrabasic rocks. The predominating types are feldspar-rich norite, pyroxenite, harzburgite (saxonite) and serpentine.

Selukwe: Chromite occurs in this region in talc schists and serpentines which are associated with related carbonate rocks. The chromite-bearing rocks of the Selukwe complex are exposed in masses of irregular outlines, bordered by acid rocks, chief among these latter being the Mont D'Or granite.

Makwiro: Most of the writer's information regarding the paragenesis of the chromite ores of the Great Dyke was obtained by a study of a suite of rocks from the Netherfield farm, Makwiro. These rocks were sent the writer by H. B. Maufe, Director of the Geological Survey of Southern Rhodesia.

In the vicinity of Makwiro, a narrow and quite uniform strip

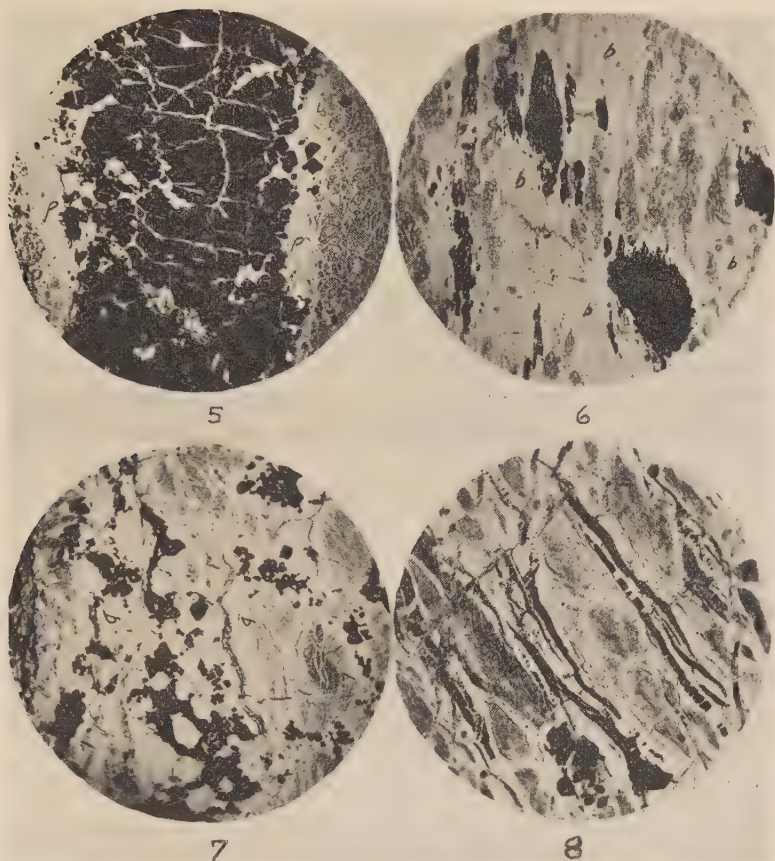


FIG. 5. A chromite veinlet bordered by penninite (*p*). The olivine groundmass on right side of veinlet does not show as much magnetite dusting as that on the left side. Wood's Mine, Pennsylvania. $\times 35$.

FIG. 6. Chromite of late crystallization, with its longest dimension parallel to enclosing bastite (*b*) fibers. Darker gray material (*m*) is magnesite. Jenkin's Pit, State-Line Serpentine Belt. $\times 15$.

FIG. 7. Chromite of late magmatic period occurring interstitially between enstatite (now bastitized). Rhodesia. $\times 15$.

FIG. 8. Chromite of hydrothermal stage restricted to central portion of bastite zones. (This is from same slide as Figure 1). Rhodesia. $\times 15$.

of harzburgite borders the dike on both sides and separates it from the granite mass. Tongues of chromite-bearing serpentine occur between the harzburgite and the overlying pyroxenite, and extend from north of the Hunyani river. The general trend of the serpentines, which lens out near Makwiro, is comparable to the harzburgite-granite contact. The pyroxenite, which overlies the serpentine, is capped by an equally thick feldspar-rich norite that forms the norite plateau.

Considerable bastite has been developed in the harzburgite. Chromite grains are grouped in aggregates in the bastite ground-mass as illustrated in Fig. 7. The transitional phase between the harzburgite and the chromite seam shows an increase in the size of such accumulations of chromite. Two modes of occurrence of chromite are noted in the transitional rocks: (1) vein chromite, black in color, traversed by numerous thin fractures filled with serpentinous material, and (2) patches of rather closely compacted anhedral to subhedral grains of black chromite in bastite. Considerable chromite is developed in the bastite zones of the footwall and differs in color from the chromite of the veinlets and accumulations. Three types of veinlets are noted in the footwall rock: (1) parallel to the original enstatite cleavages, with tongues projecting into and parallel to fibration of the bastite (Fig. 8); (2) cutting across fibration of the bastite, which is normal to the cleavage of the original enstatite; and (3) thinner veinlets of chromite which have been developed along planes of movement which offset the first type. Chromite of the second type is undoubtedly later than the silicate minerals. Feathery edges and open-textured grains indicate that there has been abundant solution of the chromite. Such solutions deposited the hydrothermal chromite in the bastite zones.

A study of thin sections together with consideration of the form of the deposits of the Great Dyke leads to the conclusion that these chromite deposits represent accumulations of late magmatic origin. Keep¹⁰ has endeavored to explain the alternation

¹⁰ Keep, F. E., "Interim Report on the Geology of the Chromite Deposits of the Umvukwe Range, Lomagundi District," S. Rhodesia Geol. Surv. Short report, 23, 1928.

of layers of chromite with layers of barren rock as caused by processes analogous to oil flotation. Such a view is regarded as entirely untenable by the writer in view of the complete absence of evidence of vertical convection currents. Keep also believes that the formation of the synclinal structure of the dike has been caused by swelling of the rock due to serpentinization. It is difficult to visualize how a depressional type of structure might be produced by swelling of underlying rocks.

Insofar as the Great Dyke chromite deposits are concerned the writer is of the opinion that the larger masses of chromite are due to gravitational differentiation which took place during the late stages of magmatic segregation. Chromite of hydrothermal origin is confined to bastite and serpentinous products and chromite of late magmatic origin is now indicated by the gathering of crystals in accumulative structures determined by resorption of original groundmass minerals.

Australia.—Through the courtesy of Wm. Baragwanath, Director of the Victoria Geological Survey, the writer has been enabled to study specimens of the chromiferous rocks of Victoria. These rocks are highly altered and are almost completely serpentinized. The presence of much bastite suggests either enstatite or bronzite as the original mineral, but the peculiar mesh-like structure of the serpentine indicates that fairly large amounts of olivine also occurred in the original rock. Thiele,¹¹ in discussing the chromite of the Dolodrook area, says:¹²

Chromite is recognized both as a secondary and an original constituent of igneous rocks, but it would appear that the Dolodrook occurrence most probably indicates a particularly fine example of magmatic segregation, in which olivine, pyroxene, corundum and chromite all represent different phases.

The writer is in accord with Thiele's views in general but suggests that other features are indicated. There is strong evidence of solution and redeposition of early magmatic chromite. Thiele

¹¹ Thiele, E. O., "Notes on the Dolodrook Serpentine Area and the Mt. Wellington Rhyolites, North Gippsland," *Roy. Soc. Vict., Proc.*, 21 (n. s.), 1907, pp. 249-267.

¹² *Idem*, p. 261.

is inclined to follow Pratt in arriving at his ideas of origin chiefly because of the association of chromite and corundum. The color of the chromite in thin section varies from translucent yellow picotite to the reddish or coffee brown chrompicotite. The two types are seen in the Victorian slides. Peripheral inclusions of bastite in the chromite indicate an overlap in the periods of crystallization of the enstatite and the chromite. Small, discontinuous stringers of chromite associated with fibers of brucite and bastite offer further evidence of solution of magmatic chromite and its redeposition under hydrothermal conditions.

New Caledonia.—Power¹³ mentions that the chromite of New Caledonia occurs in masses in the joint planes of the serpentine. Because of this type of occurrence, and the fact that there is no sharp line of demarcation between ore and the enclosing serpentine, Power is inclined to regard the ore as having been formed in natural water channels. He did not believe, however, that such solution channels could have existed at the time of solidification of the igneous mass.

The paragenetic study of New Caledonian chromiferous rocks does not suggest that the chromite was injected into the already serpentized rocks. The writer has found that the chromite grains are all highly fractured and show well defined mitred-structure. Cracks in the chromite are filled with either k  mmererite or antigorite. The interlocking boundaries of chromite and olivine suggest contemporaneity of crystallization of these minerals. That the chromite was developed before serpentization is indicated by the high degree of fracturing of the ore mineral and the filling of these fractures by serpentinous materials. Embayments in the chromite are commonly filled with k  mmererite. This suggests that during the processes of serpentization some solution of the chromite occurred. K  mmererite was thus formed instead of antigorite.

The occurrence of chromite in the joints of the serpentine, as outlined by Power, is not unlike the occurrences of the State-Line chromite deposits or those of the Bare Hills, Maryland,

¹³ Power, F. D., "Mineral Resources of New Caledonia," *Am. Inst. Min. Engrs. Trans.*, 8, 1899-1900, pp. 439-442.

region. All these types may probably represent pipe-like injections of chromium-rich differentiates into an already solidified phase of the parent ultrabasic magma.

THE ORIGIN OF CHROMITE.

Criteria on Which Conclusions Are Based.

1. *Degree of Fracturing of Grains.*—Chromite of early magmatic crystallization is seldom fractured but grains in hydrothermally altered rocks may or may not be fractured. Lack of fracturing in the chromite grains may only be used as a criterion of chromite of later origin if other evidence of later crystallization is available.

2. *Chromite of Late Magmatic Stage.*—*a.* Occurrence in zones of granulation in comparatively fresh or slightly altered olivine rocks, as in Alaska, Balsam Gap, N. C., and Selma, Oregon.

b. Disseminated grains of chromite in fractures of fresh or altered olivines, or in streaks cutting olivine, or in cleavages of enstatite (Fig. 9).

c. Elongated grains of chromite between individual minerals of the groundmass (Fig. 2 and 7).

d. Euhedral grains of chromite moulded on olivine crystals, as noted by Harker in his discussion of the rocks of Rum, and by the writer in some of the peridotites of Skye.

e. Anhedral grains of chromite, fractured or unfractured, showing apophyses into altered and unaltered minerals of the groundmass.

f. Accumulations of crystals, such occurrences having been termed "synneusis structure" (a together-swimming) by Vogt (Fig. 1).

Bowen is not in accord with Vogt's idea of the formation of such structures. He¹⁴ discusses the development of chromite and picotite by crystal accumulation and believes that no high temperature is necessary. The process involves the formation of a spinel by reaction of olivine and basic plagioclase with a liquid of non-extreme (basic) composition. The spinel thus de-

¹⁴ Bowen, N. L., *op. cit.*

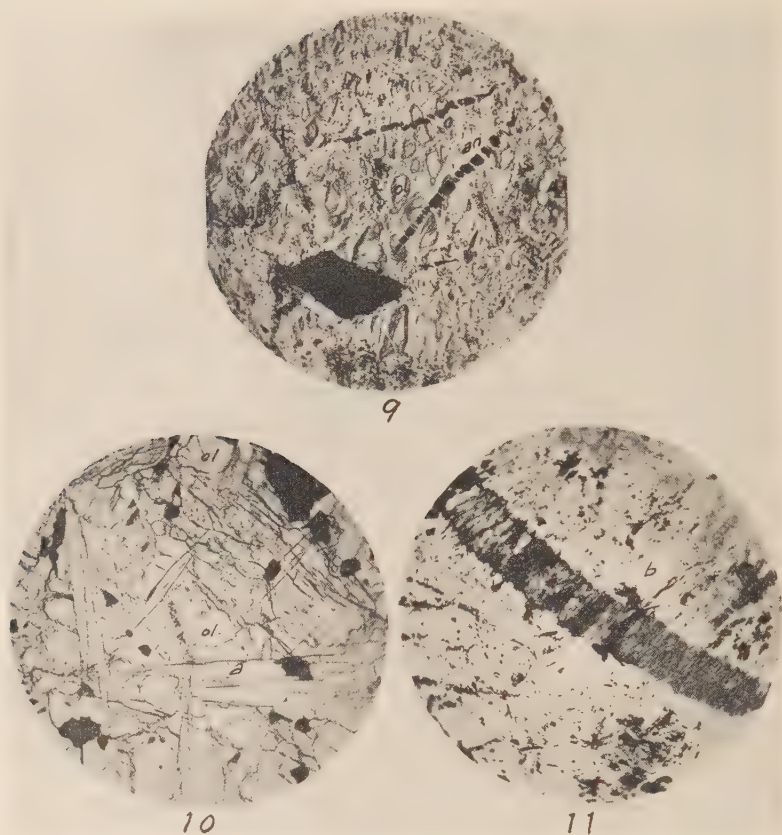


FIG. 9. Veinlet of late magmatic chromite traversing an olivine groundmass now partially antigoritized (*an*). From the Line Pit, State-Line Serpentine Belt. $\times 15$

FIG. 10. Chromite of the hydrothermal stage associated with actinolite (*a*) occurring in a fairly fresh olivine groundmass. Chromite grain, upper left, is interstitial between olivine grains. In lower left, chromite cuts across olivine grain. North Carolina. $\times 15$.

FIG. 11. Chromite of hydrothermal origin enclosed in a magnesite veinlet traversing a bastitized (*b*) groundmass. (From same slide as Figure 6). Jenkin's Pit, State Line Serpentine Belt. $\times 15$.

veloped is a transient phase. Olivine is incapable of containing any considerable amount of chromic oxide and this oxide cannot enter in important amounts until a monoclinic pyroxene is developed. Crystal fractionation goes on and chromite and picotite may be developed locally. The excess material thrown out in the reactions described may be deposited in euhedral crystal accumulations as a sort of a pseudomorph after an earlier, resorbed mineral. Such accumulations are noted in the Rhodesian slides, and in the same slides hydrothermal chromite is developed in bastite.

3. *Chromite of the Hydrothermal Stage*.—Chromite of this stage is deposited along:

- a. cleavages of the deuteric minerals as penninite, actinolite, talc and kämmererite (Fig. 10);
- b. bastite zones (Fig. 6);
- c. fibers of chrysotile veinlets; and
- d. magnesite veinlets (Fig. 11).
- e. Outlines of chromite are bordered by serpentine in entirely fresh rocks, as described from Dunsmuir, California.

4. The emplacement of the ore bodies is suggestive, in part, of chromite being introduced into the surrounding rock. Zavaritsky¹⁵ has recently pointed out that the form and position of chromite grains indicates deposition in a mobile medium.

The types of occurrence of chromite deposits may be grouped under five general heads.

- (a) Pipe-like or ore-shoot-like bodies.
- (b) Sill-like bodies.
- (c) Schlieren.
- (d) Pockets or lenses.
- (e) Placers (not considered in this discussion).

Pipe-like Bodies: These are well illustrated by the occurrences at the famous Wood Mine and the Line Pit deposits. In the latter case the pipe had a diameter of 6 to 8 feet and was completely sheathed by a zone of williamsite one foot in thickness. Antigorite is commonly associated with the chromite of Line Pit

¹⁵ Zavaritsky, A. N., "Primary Platinum Deposits of the Urals," Russia. Comité Géol. Mat. pour la géol. gen. et appl., livr. 108, 1928.

and the chromite shows apophyses into the groundmass minerals. It is thus indicated that the chromite is probably of late magmatic origin. The gradation from a wehrlitic rock into a saxonitic type is sharp. The gradation from pure ore into williamsite is likewise abrupt. The ore body and the adjacent serpentine may represent basic differentiation products intruded into earlier formed peridotitic rocks toward the end of the magmatic period.

Sill-like Bodies: These are best illustrated by the occurrences in the Great Dyke of Southern Rhodesia and in the Bushveld Complex. In some cases, the serpentine borders of the chromite seams carry considerable ore mineral but rich zones seldom reach a width of more than four inches. The serpentine beyond the chromite vein is seldom enriched in chromite.

The current idea of formation regarding these African deposits is that they have been formed by gravitational differentiation. It would appear, however, that other processes must be involved to account for the layering.

Schlieren: This type of deposit is apparently not restricted to any one locality. One might assume that subsequent to the formation of a crystal mesh by fractionation, crystallization deformation movements, induced by earth pressures or by downward pressure of the overlying rocks or the magma itself, may result. Such movements would tend to "squirt" the interstitial liquor from the crystal mesh into regions of lesser pressure and form ill-defined streaks which are later in their period of formation than the enclosing rock.

Pockets and Lenses: The Bare Hills occurrence of chromite, the deposits of North Carolina and Norway are examples of this type of deposit. Only in the North Carolina localities are these deposits marginal. Lewis believed that convectional currents set up because of the temperature gradient between the cooler walls and the hotter portions of the magma would diffuse chromic oxide molecules toward the cooler walls. A lowering of the temperature would decrease the fluidity of the magma and such diffusion concentration would be insignificant. The writer believes that pockets or lenses of the ore might be formed by a process similar

to that believed to have been effective in the formation of synneusis or accumulative structures.

Previous Interpretations.

The earliest investigators, who attempted to unravel the history of chromite, believed that it was formed through the decomposition of chromium-bearing peridotites. Among those who supported such an idea were Arzruni,¹⁶ von Groddeck,¹⁷ de Launay¹⁸ and others. Von Groddeck suggested that the formation of chromite deposits was contemporaneous with the serpentinization of the original rocks, dunites and peridotites. He believed that any iron liberated from the magnesian silicates would react with primary minerals carrying chromic oxide, such as chrome-diopside, picotite and others, to form chromite. Meunier¹⁹ regarded the occurrences of native iron of Disco Island, of platinum and of chromite deposits, as formed by pneumatolytic processes wherein chlorides of platinum, nickel, iron and chromium played an important role. He believed that these processes followed closely after the intrusion of the magma. His views, were shared, in part, by de Launay.

Vogt²⁰ developed the idea of magmatic segregation as the only answer for the origin of chromite. He had then, and still has, an ample following in Pratt, Hall, Diller, Lewis, Humphrey and others. Rosenbuch was convinced, from a petrographic standpoint, that chromite, commonest in magnesia-rich rocks of the Archean, was like magnetite in that it belonged to the first generation of crystals. This early crystallization of chromite is indicated by the fact that it is usually enclosed by the next oldest

¹⁶ Arzruni, A., *Geol. d. Wiss. Christiania*, 1873.

¹⁷ Groddeck, A. von, "Die lehre von den lagerstätten der erze," Leipzig, 1879.

¹⁸ Launay, L. de, "Gites minéraux et métallifères," 1913, p. 257.

¹⁹ Meunier, Stanislaus, "Contribution a l'histoire du fer chrome," C. R. 110, 1890, pp. 424-425; VII. Int. Geol. Cong. 1897, p. 157.

²⁰ Vogt, J. H. L., "Bildung von Erzlagerstätten durch Differentiationsprocesse in basischen Eruptivegesteinmagmata," *Zeit. f. prak. Geol.*, 1893, pp. 4-11; 125-143; 257-284. "Beiträge zur genetischen Classification der durch magmatische Differentiationsprocesse und Pneumatolyse entstandenen Erzvorkommen." *Zeit. f. prak. Geol.*, 1894, pp. 384-393.

constituent, olivine. The greatest advance in the existing classification of ore deposits was made by Vogt in 1894 when he published his grouping of ore deposits:

- I. Magmatic differentiation.
 - a. Native metals.
 - b. Oxidic Ores.
 - c. Sulphidic Ores.
- II. Pneumatolytic.

He included chromite under I-b on the basis of his study of the unaltered rocks of Hestmandø, Norway. He considered chromite to be the oldest mineral because of its euhedrism, and he stressed the point that in all cases the chromite appears to be the earliest consolidated constituent. In his co-operative work with Beyschlag and Krusch,²¹ he says:

The chromite deposits in peridotite show accordingly the same geological, petrographical and morphological characters as those of titaniferous iron in gabbro, and the general statements afterwards enumerated in connection with the titaniferous iron deposits hold good also for the occurrence of chromite.

Lindgren,²² in accepting Vogt's idea in regard to many ore bodies, expressed the opinion that chromite might be secondary in some cases and formed from picotite, chrome-diopside or primary chromite during the processes of serpentinization.

The statements of Vogt had little effect on Power²³ who, after a study of the New Caledonian mineral resources, held to the idea that chromite represented material formed during the natural process of oxidation accompanying the hydration and weathering of the original ultrabasic rocks.

Hall and Humphrey²⁴ regard the chromite deposits of the

²¹ Beyschlag, F., Krusch, P., and Vogt, J. H. L., "The Deposits of the Useful Minerals and Rocks," . . . tr. by S. J. Truscott, 1914, p. 246.

²² Lindgren, Waldemar, "Mineral Deposits," N. Y., 1913, p. 747.

²³ Power, *op. cit.*

²⁴ Hall, A. L., and Humphrey, W. A., "On the Occurrence of Chromite Deposits along the Southern and Eastern Margins of the Bushveld Plutonic Complex," *Geol. Soc. South Africa, Trans.*, 11, 1908, pp. 69-77.

Transvaal as local segregations or concentrations of grains brought about by differentiation of the magma of the Bushveld Complex. They point out that chromite shows perfect crystal outlines and these encroach on other minerals. The next endorsement of the theory of magmatic segregation of chromite was by Cirkel,²⁵ who said:

. . . the actual formation of chromite must have been effected during the cooling or solidification of the magma under conditions which cannot be sufficiently explained.

The foregoing ideas represent those who have supported or opposed the magmatic segregation theory of the formation of chromite.

In 1916 it was suggested by Tolman and Rogers,²⁶ following an exhaustive study of sulphide ores, that in many cases the ore minerals were introduced subsequent to the crystallization of the primary silicates. In fact, the introduction of such ores marked the third step in the orderly series of events recognized by these writers. Their sequence is:

- a. Crystallization of primary silicates;
- b. Development of hornblende and biotite, and occasionally tourmaline, garnet, as magmatic alteration products;
- c. Introduction of ore minerals;
- d. A small amount of rearrangement of the ores and the development of secondary silicates by hydrothermal waters.

They question the interpretation that Vogt gives for his figures, and state: "Examination of his figures shows irregular as well as subhedral forms; and the alternate hypothesis that chromite octahedra are formed at a late stage is worthy of consideration."

The present writer raises the same question regarding Diller's interpretation of the forms of chromite in the Dunsmuir, California, slides and on his sequence of crystallization of the ore and the groundmass-minerals.

²⁵ Cirkel, Fritz, "Report on the chrome iron deposits in the eastern townships, province of Quebec." Can. Dept. Mines. Mines Branch. Ottawa, 1909.

²⁶ Tolman, C. F., and Rogers, A. F., "A Study of Magmatic Sulfid Ores," Leland Stanford Jr. Univ. Publ. 1916. Summary T. No. 1.

Singewald,²⁷ commenting on the work of Tolman and Rogers, stressed the point that the French school, ably headed by de Launay, had always recognized the role of mineralizers in the formation of ore deposits, and that though accessory ore minerals may precede rock minerals, even in the so-called magmatic segregations the ore minerals are later than the rock-forming minerals. Thus the French school recognizes no gap in the mineralization between the freezing of the original molten magma and the deposits formed through the extraction of material from the magma by mineralizers. Singewald was of the opinion that a paragenetic study of the chrome ores would show that the chromite was not an early magmatic mineral but that it also formed mainly later than the non-metallic minerals of the igneous rock. The present writer has found that many of the low grade Rhodesian ore specimens show chromite occurring interstitially between groundmass minerals (Fig. 7).

The ideas of origin of the chromite deposits of Oregon advanced by Westgate²⁸ and those that Gordon²⁹ has promulgated for the State-Line serpentines are essentially the same. The general plug-like shape of the chrome-ore body of the Line Pit (State-Line Serpentine Belt) is suggestive of a later period of formation than the surrounding rock. The present writer's study of thin sections from this pit strengthens this idea. Euhedral forms of chromite are almost lacking and the outlines of the grains, irregular and feathery, show apophyses into the groundmass minerals. This indicates that chromite crystallization was either contemporaneous with, or later than, the formation of the groundmass minerals of the plug.

Westgate suggests that, in the case of the Oregon deposits, differentiation took place at a good distance below the present land surface, and chromite deposits and peridotite resulted from the split-off of the general magma, but not from the same stock that

²⁷ Singewald, J. T., Jr., "Magmatic Segregation and Ore Genesis," *Min. and Sci. Press*, 114, 1917, pp. 733-736.

²⁸ Westgate, L. C., *op. cit.*

²⁹ Gordon, S. G., "Chromite Deposits of the State-Line Serpentines," *Acad. Nat. Sci. Phila. Proc.*, 73, 1921, pp. 449-454.

is represented by the pyroxenite. He believed that differentiation in place was a subordinate factor in the formation of the ore.

Conclusions Based on Present Study.

The following sequence of crystallization is recognized in the chromiferous rocks.

1. Crystallization of early magmatic chromite is well advanced before the initial crystallization of the groundmass minerals. Final freezing of early magmatic chromite overlaps the formation of the groundmass silicates.

2. Crystallization of late magmatic chromite which replaces, either partially or completely, the groundmass minerals, and surrounds, embays, or cuts these minerals, or penetrates the cleavable minerals. *Chromite formed during this period in greater quantity than during the other periods.*

3. Chromite of the hydrothermal period, which is more important in some deposits than in others, is distinctly later than the magmatic period and is associated with two distinct groups of minerals: (a) Early hydrothermal minerals—Anthophyllite, actinolite, and tremolite; (b) Late hydrothermal minerals—Chlorite, talc, kämmererite, penninite, serpentine and magnesite.

Chromite of this period was probably derived by the hydrothermal solutions from the parent rock or from other rocks which they traversed. The rounded outlines of the chromite of the early, and possibly the late, magmatic stage are suggestive of corrosive action by hydrothermal solutions. The chromium thus obtained has been deposited in bastite zones, chrysotile fibers, in magnesite, between kämmererite or penninite plates, and in the cleavages of the early hydrothermal minerals.

It is difficult to determine accurately the amount of chromite deposited along cleavages or interstitially between plates of deutric minerals by hydrothermal solutions. In Fig. 6, chromite occurs with its longest dimension parallel to the direction of the bastite zones, and apophyses of chromite project into the bastite. Such chromite might have been deposited also as a product of late mag-

matic origin along the cleavages of the original silicates (enstatite in the example noted) before their alteration to serpentine.

The largest deposits of chromite are in serpentized rocks, and this suggests that the concentration of the ore mineral is proportional to the amount of serpentization that the original chromiferous rock has undergone. This implies that the hydrothermal solutions, which produced the serpentization, carried and deposited the chromite. The only apparent sources of such chromium is either in the reworking of earlier formed chromite or in waters of meteoric origin.

Some authorities believe that an ultrabasic magma is incapable of supplying enough water to produce serpentization but believe that the necessary waters may be derived from the complementary acid phases of a cooling basic mass. The State Line serpentines, which show excellent examples of hydrothermal chromite, are cut by albitite dikes that are not deformed and are later than serpentization. This process of alteration is a later hydrothermal one and is probably produced by greater concentration of solutions from sources that were deeper in the cooling mass than those that produced the earlier hydrothermal minerals, actinolite, tremolite and anthophyllite. The exact position of serpentization in the series of events beginning with the crystallization of the magma and ending with the latest hydrothermal action is not known.

4. A study of the chemical composition of chromite from different localities indicates that there is no apparent correlation between:

- a. the composition of chromite and its mode of occurrence;
- b. the composition and sequence of crystallization of the chromite and the groundmass minerals; and,
- c. the composition of chromite and the degree of alteration of the chromiferous rock.

It is further indicated that the mineral called chromite cannot be expressed by a definite chemical formula.³⁰

³⁰ Fisher, L. W., "Chromite: Its Mineral and Chemical Composition." (In press—*Amer. Min.*)

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SUMMARY.

The notion that chromite deposits have originated through primary crystallization *in situ* has been greatly overemphasized. Chromite of the late magmatic period is of much greater importance than that of the early magmatic period. Hydrothermal solutions causing serpentinization have played an important role in the formation of chromite deposits by dissolving magmatic chromite and redepositing it with the hydrothermal silicates.

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VITA.

Lloyd Wellington Fisher was born on February 15, 1897, in the city of Reading, Pennsylvania. He attended the public schools of that city, and was graduated from the high school in 1915. In 1916 he entered Lehigh University, Bethlehem, Pennsylvania, and received the degree of Bachelor of Arts in 1921. His course at Lehigh was interrupted by service in the Medical Corps of the U. S. Army from May, 1918, until July, 1919, during which time he was stationed at Columbus Barracks, Ohio.

He was teaching fellow in the Department of Geology of Pennsylvania State College, during the academic year of 1921-1922, and received the degree of Master of Science from that institution in 1923. From September, 1922, until June, 1923, he was assistant instructor in mineralogy at Syracuse University. He was appointed instructor in geology at Brown University in September, 1923, and served in that capacity until June, 1927. For the past two years he has been a graduate student in the Department of Geology of the Johns Hopkins University. During the first year of graduate work he held the Ella Slack scholarship and was granted a University scholarship during his second year of residence. He is at present Head of the Department of Geology at Bates College, Lewiston, Maine.

He was elected to full membership in the Society of the Sigma Xi at Brown University in 1925, and to the Gamma Alpha at the Johns Hopkins University in 1928.

During the summer of 1921 he made a reconnaissance survey of the Helderberg limestone of Pennsylvania for the Geologic Survey of that State. He was instructor in geology and mineralogy on the Lehigh University mining trip that visited mining localities in Canada, Michigan, Illinois, West Virginia and Pennsylvania, in 1924. He has acted as consulting geologist for several stone companies in the vicinity of Reading during the summers of 1925 and 1926, and assisted Dr. Benj. L. Miller, consulting geologist for the Allentown Portland Cement Company, dur-

ing a portion of the summer of 1927. In 1928 he was engaged by the Corps of Engineers, U. S. Army, to make geologic investigations at proposed dam sites in the Tennessee and Cumberland River Basins.

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2. "Applications of Colloid Chemistry to Mineralogy." Part I (with F. L. Simons), Amer. Min., Vol. 11, 1925, pp. 124-130; and Part II (with F. L. Simons), Amer. Min., Vol. 11, 1926, pp. 200-206.
3. "Notes on the Mineral Localities of Rhode Island." Part I (with E. K. Gedney), Amer. Min., Vol. 11, 1926, pp. 334-339, and Part II (with C. G. Doll), Amer. Min., Vol. 12, 1927, pp. 427-436.
4. "Quartz from Iowa Canyon, Nevada." Amer. Min., Vol. 12, 1927, pp. 225-226.
5. "Variations in Crystal Forms." "A Study of Lead Bromide and Lead Iodide." Amer. Jour. Sci., Vol. XV, 1928, pp. 39-48.
6. "Geologic Examination of Dam Sites in the Tennessee and Cumberland River Basins." (With R. D. Ohrenschall.) Paper read before the annual meeting of the A. I. M. E. in New York, February, 1929. Published in a current number of the journal of that society.
7. "Origin of Chromite." (Presented before the Geological Society of Washington, Apr. 10, 1929.) (Abstract submitted to the Jour. Wash. Acad. Sci.)
8. "Chromite—Its Paragenesis, Mineral and Chemical Composition." (Deposited in the library of the Johns Hopkins University, Baltimore, Maryland, June, 1929.)
9. "Chromite—Its Mineral and Chemical Composition." Amer. Min., Vol. 14, 1929, pp. 341-357.

